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## CONVEXITY, MAGNIFICATION, AND TRANSLATION: THE EFFECT OF MANAGERIAL OPTION-BASED COMPENSATION ON CORPORATE CASH HOLDINGS

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### Abstract

Using the distinctions among the convexity, magnification, and translation effects, we identify the pertinent parameters and examine empirically the relation between cash holdings and option-based managerial compensation. We show that changes in delta reduce the effects of magnification and convexity on managerial risk aversion. We also provide evidence that there is a negative relation between the option-based incentives delta and vega and cash holdings. These results are robust when incentives are extended to include all executive board members and when the sample is broken down according to different risk characteristics.

*JEL Classification:* F30, F32, G32, G33

### I. Introduction

The growing interest in executive compensation and agency problems has spawned a large and increasing literature that looks at the option-based incentives embedded in managerial compensation and examines their effect on corporate financial decisions. This literature is motivated by the assumption that the convex compensation schedule of an option can offset the concavity of the utility function of an underdiversified and overly risk averse manager and make him or her less risk averse (see, e.g., Haugen and Senbet 1981; Smith and Watts 1982; Smith and Stulz 1985; DeFusco, Johnson, and Zorn 1990; Billett, Mauer, and Zhang 2010). Ross (2004, p. 207), however, shows that “without further conditions on utility functions beyond monotonicity and risk aversion, this is not correct” and that, in fact, the opposite can be true. He shows that when examining the relation between option-based incentives and corporate decision making three distinct effects should be considered. The first, called the convexity effect, is how the individual option-based incentives affect managerial risk aversion at a given level of wealth. The second, called the magnification effect, reflects how different levels of exposure to the firm’s share price affect managerial risk aversion. The third, called the

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translation effect, is how different levels of wealth affect managerial risk aversion. Failure to make these distinctions in empirical applications can lead to problems of model misspecification and erroneous inference. No empirical study (that we know of) in the extant literature on the relation between option-based compensation and corporate financial decisions has formally made these distinctions.

Cash holdings are particularly adapted to the study of managerial incentives and corporate decision making because the decision to deploy or accumulate cash in excess of what is necessary to meet the needs of normal business transactions and any contractual obligations such as liquidity covenants is to a large extent at the discretion of managers with little scope for external scrutiny.<sup>1</sup> Thus, given the propensity for accumulated cash to lower firm risk (Kim, Mauer, and Sherman 1998; Opler et al. 1999; Ozkan and Ozkan 2004), it is an excellent instrument for a manager seeking to implement personally advantageous corporate policies that are inconsistent with the risk preferences of shareholders. This is reflected in the fact that it has figured prominently in the recent compensation literature (e.g., Chava and Purnanandam 2010; Liu and Mauer 2011; Tong 2010).

As in several recent studies that use the concepts of vega and delta<sup>2</sup> from option pricing theory to examine the relation between managerial financial decisions and managerial risk incentives (e.g., Guay 1999; Coles, Daniel, and Naveen 2006), there is no consistent evidence in the cash holdings literature of how and why vega and delta affect managerial behaviour. For instance, Chava and Purnanandam (2010) document a significant positive relation between chief executive officer (CEO) delta and cash holdings, and an inverse relation between CEO vega and cash holdings. Tong (2010) documents a significant negative relation between CEO delta and vega and cash holdings, whereas Liu and Mauer (2011) provide evidence of a weak negative relation between delta and cash holdings but a strong positive relation between vega and cash holdings. The authors argue that their results support the argument of increased precautionary cash holdings to avoid costly external funding as well as a higher cost of debt to satisfy debt holders.

These conflicting arguments, and mixed results warrant further investigation and analysis, especially with respect to the apparent contradictory interpretations of vega and delta. For example, in the studies presented above, both vega and delta can either be risk-inducing incentives or proxies for increased risk aversion. In Chava and Purnanandam (2010) vega is the option incentive that reduces cash holdings and delta is the risk aversion proxy that increases them. In Liu and Mauer (2011) vega is risk reducing and delta is risk inducing. In Tong (2010) both vega and delta are risk-inducing incentives.<sup>3</sup>

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<sup>1</sup> See Liu and Mauer (2011) for a discussion of the relation between cash holdings and covenants.

<sup>2</sup> Vega corresponds to the change in managerial wealth with respect to the change in the volatility of the firm's returns whereas delta corresponds to the change in managerial wealth with respect to a change in the value of the firm's stock. It is well known in option pricing theory that an increase in the riskiness of a standard option's underlying asset increases the value of the option.

<sup>3</sup> Similar results can be found in other sectors of the corporate compensation literature. Coles, Daniel, and Naveen (2006) on a wide array of corporate policies, Brockman, Martin, and Unlu (2010) on the maturity structure of corporate debt, Grant, Markarian, and Parbonetti (2009) on accruals management, and Knopf, Nam, and Thorton (2002) on corporate hedging use vega as a risk-inducing incentive and delta as a risk-reducing incentive. However, Daniel, Spencer, and Naveen (2004) on the pricing of debt and equity find that both vega and delta are risk inducing.

We resolve some of the foregoing contradictions and extend the literature by developing an innovative empirical model based on the Ross (2004) results that distinguish among the convexity effect, the magnification effect, and the translation effect. This makes it possible to identify the relevant option-based incentives and their effect on managerial risk aversion and specify how each affects cash holdings. Our findings provide explanations for some of the discrepancies in the outstanding literature and have important implications for corporate policies and legislative regulations on executive compensation.

Using the Black–Scholes option pricer to estimate option values, deltas, and vegas, we show that the convexity and magnification effects reduce managerial risk aversion. We also identify the change in delta as a key variable and show that it is negatively related to the reduction in risk aversion. The implication is that the alignment of managerial and shareholder interests that comes about through lower risk aversion, which induces managers to lower cash holdings in favor of riskier assets, is reduced by increases in delta. As in Ross (2004), the translation effect depends on the managerial utility function.<sup>4</sup> For utility functions with decreasing absolute risk aversion (DARA), the most common assumption, its effect is negative. Its effect is positive with increasing absolute risk aversion (IARA) and neutral with constant absolute risk aversion (CARA), and there is no reason why absolute risk aversion could not be constant or increasing.<sup>5</sup> For example, IARA due to low diversification would explain the undiversified manager's decision to increase cash holdings at the expense of more profitable risky assets. We show that the effect of delta and vega on risk aversion depends on the managerial utility function. The implication is that the effect of delta and vega on cash holdings depends on whether the manager has DARA, IARA, or CARA.

In the main contribution of this article, we use UK data<sup>6</sup> to provide strong empirical evidence that the change in delta is a key option-based compensation incentive that is positively related to cash holdings. The implication is that this reflects the positive relation between the change in delta and risk aversion due to its effect on magnification and convexity. We also provide evidence that because of the significant negative relation between delta and vega and cash holdings, UK managers generally exhibit DARA. These results are robust with respect to alternative specifications, when incentives are extended to include all executive board members and when the sample is broken down according to different risk characteristics. We show that omitting the change in delta as an explanatory variable renders delta insignificant as an explanatory variable, an indication of potential misspecification in models where the change in delta is not included.

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<sup>4</sup> Ross (2004) calls this moving the evaluation to a different part of the domain of the original utility function where the utility function can have greater or lesser risk aversion.

<sup>5</sup> The link between wealth and risk aversion depends on the utility function. For example, when Becker (2006) uses wealth to proxy for risk aversion, he implicitly assumes DARA.

<sup>6</sup> The United Kingdom is particularly interesting for the testing we propose. It has strong shareholder protection similar to that of the United States, but evidence in the corporate governance literature suggests that firm-level mechanisms, such as corporate boards, are poor monitors of managerial actions (see Weir, Laing, and McKnight 2002; Ozkan and Ozkan 2004). Thus, in the absence of effective firm-level monitoring mechanisms, managerial compensation incentives might have more importance.

## II. Model Development

The Ross (2004) analysis of the effect of convex compensation structures and managerial attitudes to risk are based on the Pratt (1964) measure of absolute risk aversion and the assumption that managers are risk averse. Risk aversion means that each manager has a utility function  $u(w)$  satisfying the following conditions:

$$u'(w) \geq 0, u''(w) \leq 0, \forall w, \quad (1)$$

where primes denote first and second derivatives with respect to wealth, denoted as  $w$ . Utility functions such as these are strictly concave. Pratt shows that maximizing the expected utility of a risk-averse economic agent is approximately equal to:

$$A = -\frac{u''(w)}{u'(w)}, \quad (2)$$

where  $A$  represents the degree of absolute risk aversion and measures how much the economic agent (in the case of Ross, the manager) dislikes the uncertainty he faces.  $A$  can be increasing in  $w$  (the first derivative with respect to  $w$  is positive<sup>7</sup>), decreasing in  $w$  (the first derivative with respect to  $w$  is negative<sup>8</sup>), or constant (the first derivative with respect to  $w$  is zero<sup>9</sup>). This gives rise to the terminology increasing, decreasing, and constant absolute risk aversion (IARA, DARA, and CARA respectively).

Starting from here, Ross defines the derived utility function as  $u(f(x)) = v(x)$ , where wealth ( $f$ ) is a derivative security whose value depends on the value of an underlying asset denoted as  $x$ . The derived coefficient of absolute risk aversion is given as:

$$A_v(x) = -\frac{v''(x)}{v'(x)}. \quad (3)$$

Ross shows that whether the derived utility function is more or less risk averse than the original depends on three effects—the convexity effect, the magnification effect, and the translation effect—where the net effect on risk aversion can be measured as:

$$A_v(x) - A(x) = \text{Convexity effect} + \text{Magnification effect} + \text{Translation effect}. \quad (4)$$

The convexity effect measures how the payoff schedule of the wealth function affects managerial risk aversion. For example, the convexity of a payoff schedule like a call option clearly makes risky bets more desirable. It is defined as:

$$\text{Convexity effect} = -\frac{f''(x)}{f'(x)}. \quad (5)$$

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<sup>7</sup> IARA implies  $\frac{dA}{dw} = \left[ -\frac{u''(w)}{u'(w)} \right]' > 0$ .

<sup>8</sup> DARA implies  $\frac{dA}{dw} = \left[ -\frac{u''(w)}{u'(w)} \right]' < 0$ .

<sup>9</sup> CARA implies  $\frac{dA}{dw} = \left[ -\frac{u''(w)}{u'(w)} \right]' = 0$ .

The magnification effect reflects how different levels of exposure to the firm's share price affect managerial risk aversion. It is defined as:

$$\text{Magnification effect} = A(f)[f'(x) - 1]. \quad (6)$$

The translation effect measures how different levels of wealth affect managerial risk aversion as the fee schedule shifts or translates the evaluation of any bet to a different portion of the domain of the agent's utility function. Thus, it depends on whether the agent has DARA, IARA, or CARA. It is defined as:

$$\text{Translation effect} = A(f) - A(x). \quad (7)$$

As Ross (2004) emphasizes, one merit of this decomposition is that these three effects are locally independent, in the sense that for a given utility function, each can vary without affecting the others. We now use this insight and these three effects in the context of the Black–Scholes option pricer to develop an empirical model for testing the effect of firm-based compensation on managerial risk aversion.

Consider a manager whose firm-based wealth, denoted by  $f(x)$ , consists of a call option on one share of the firm's stock with a market price denoted as  $x$  that follows geometric Brownian motion:<sup>10</sup>

$$dx = \alpha x dt + \sigma x dz, \quad (8)$$

where  $\alpha$  is the drift parameter,  $\sigma$  is the standard deviation of  $dx/x$ , and  $dz$  is a standard Wiener process with zero mean and variance of  $dt$ .

The well-known Black–Scholes European option pricer can be used to value the call option on an asset that follows a process represented in equation (8):

$$f(x) = xN(d_1) - e^{-r(T-t)}XN(d_2). \quad (9)$$

$N(d_i)$   $i = 1, 2$  is the standard normal cumulative evaluated at  $d_1$  and  $d_2$ , where  $d_1 = \frac{\ln(x_t/X) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}}$  and  $d_2 = \frac{\ln(x_t/X) + (r - \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}}$ ;  $r$  is the risk-free interest rate;  $X$  is the strike price; and  $(T-t)$  is the time to maturity. We use the Black–Scholes option pricer because most stock options used in compensation packages are relatively simple call options. Although many do have special features, such as vesting periods or variable exercise prices, their pricing and risk management parameters, like delta and vega, play the same role as these same parameters in the plain vanilla European-style option pricers. Thus, the insights derived from the simple option pricing models can be extended to

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<sup>10</sup> For expository convenience to identify the pertinent variables and their effect on risk aversion, we consider only option-based firm wealth. It is straightforward to incorporate portfolios of individual options and outright shareholdings in the analysis because the pertinent variables for the portfolios are linear combinations of the variables of the individual options and shareholdings.

include most of the stock options included in managerial compensation packages. The Black–Scholes option pricer is the generic option pricing model that has stood the test of time and is also the simplest and easiest to apply (see, e.g., Black 1989).

In the empirical section that follows we want to examine the relation between firm-based compensation incentives and cash holdings. The argument is that corporate cash holdings are partly determined by the effect of the payoff schedule of firm-based compensation on managerial risk aversion. As discussed above, risk aversion is affected by the payoff schedule of the wealth-generating function that is reflected in the translation, magnification, and convexity effects. Without knowledge of the specific managerial utility function it is not possible to measure risk aversion and the three payoff schedule effects directly. However, if we know the general type of utility function (DARA, IARA, or CARA) and the wealth-generating function, several interesting relations can be derived.

First, consider the convexity effect. The convexity effect of equation (5) in the context of the Black–Scholes option pricer is straightforward.  $f'(x)$  corresponds to delta and  $f''(x)$  corresponds to gamma where  $0 < f'(x) < 1$  and  $0 < f''(x)$ . Because both are positive, the convexity effect on managerial risk aversion is negative.<sup>11</sup> As discussed in the Introduction, delta figures prominently in the empirical literature on the option-based incentives embedded in managerial compensation and its effect is ambiguous. To see how delta affects the convexity effect, let delta change while holding gamma constant:<sup>12</sup>

$$\frac{d\left[-\frac{f''(x)}{f'(x)}\right]}{d[f'(x)]} = \frac{f''(x)}{f'(x)^2} > 0. \quad (10)$$

This derivative is positive because both  $f''(x)$  and  $f'(x)$  are positive. Thus, an increase in delta will reduce the effect of convexity and increase managerial risk aversion.

A similar operation can be performed on the magnification effect defined in equation (6).<sup>13</sup> Because  $f'(x)$  is positive and less than 1, the magnification effect on risk aversion is also negative. The effect of a change in delta on magnification is given by holding  $f(x)$  constant and letting delta change:<sup>14</sup>

$$\frac{d[A(f)[f'(x) - 1]]}{d[f'(x)]} = A(f) > 0. \quad (11)$$

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<sup>11</sup> The Black–Scholes formula for the delta and gamma of a European call option are, respectively,  $\Delta = f'(x) = N(d_1)$  and  $\Gamma = f''(x) = \frac{1}{\sigma x \sqrt{2\pi(T-t)}} e^{-\frac{(d_1)^2}{2}}$ .

<sup>12</sup> For example, in the context of a simple call option this can be achieved by making appropriate changes in the strike price and the option's time to maturity. In the more general context of a portfolio of options and shares the same effect can be achieved by adding an option or portfolio of options or options and shares with a different delta but the same gamma.

<sup>13</sup> Remember that for a given utility function each effect can vary without affecting the others.

<sup>14</sup> Again, this can be achieved by making appropriate changes in the strike price and the option's time to maturity.

This derivative is positive because  $A(f)$  is positive due to the risk aversion postulated in equation (1).

Thus, an increase in delta will reduce the effects of convexity and magnification and increase managerial risk aversion. This implies that if managers are using cash holdings to manipulate firm risk for their own personal benefit at the expense of shareholders, an increase in managerial delta will increase cash holdings.

The translation effect on risk aversion defined in equation (7) depends on whether the manager's utility function has DARA, IARA, or CARA. Since  $f < x$ , the effect is positive with DARA, it is negative with IARA, and it is equal to zero with CARA. To see how delta affects the translation effect, take the derivative of equation (7) with respect to  $x$ , which gives:

$$\frac{d[A(f) - A(x)]}{dx} = \left[ -\frac{u'''(f)}{u'(f)} + \frac{u''(f)^2}{u'(f)^2} \right] f'(x) - \left[ -\frac{u'''(x)}{u'(x)} + \frac{u''(x)^2}{u'(x)^2} \right]. \quad (12)$$

For CARA utility functions, both parentheses on the right-hand side of equation (12) are equal to zero, so for CARA utility functions delta does not affect the translation effect. For DARA and IARA utility functions, both parentheses have the same sign. For DARA they are negative. Thus, because  $f'(x)$  is positive, higher levels of delta increase the absolute value of the first term on the right-hand side of the equation and, consequently, decrease the translation effect (which is positive because  $f < x$ ) for utility functions with DARA. In other words,  $f'(x)$  has a negative effect on risk aversion. For IARA utility functions both parentheses are positive. Thus, higher levels of delta have a positive effect on the translation effect and risk aversion.

From this we conclude that for managers with DARA delta is negatively related to cash holdings, for managers with IARA managerial delta is positively related to cash holdings, and for managers with CARA managerial delta is not related to cash holdings. Thus, in the empirical model that we test below delta and the change in delta are important determinants of risk aversion and cash holdings, with effects that can be complementary or offsetting. In the model developed above, change in delta, through its effect on convexity and magnification, always has a positive effect on risk aversion and, as a consequence, on cash holdings. Delta itself, through its effect on translation, can have a positive, negative, or null effect on risk aversion and cash holdings depending on whether the managerial utility function is DARA, IARA, or CARA. Thus, for an unbiased estimate of the effect of firm-based compensation on managerial risk taking, both variables must be included. Consider, for example, a managerial utility function with DARA. The effect of delta will be negative and the effect of the change in delta will be positive. Omitting the change in delta will concentrate the three effects of risk aversion on delta alone, thereby affecting the estimated coefficient. If the translation effect is considerably stronger than the convexity and magnification effects, the coefficient will have the right sign but its significance will be diminished or eliminated. If the convexity and magnification effects are stronger than the translation effect, the coefficient could even change signs.

This brings up the question of vega, the change in the price of the option with respect to a change in the volatility of the stock return. Although vega does not appear



directly as a determinant of managerial risk aversion in the three effects outlined above, it could affect risk aversion indirectly through the effect of sigma on managerial wealth. It is well known in the option pricing literature that  $\text{vega} = \frac{df}{d\sigma} > 0$ .<sup>15</sup> An increase in sigma increases the manager's firm-based wealth.<sup>16</sup> The higher the vega, the larger is the increase in wealth. An increase in wealth affects risk aversion depending on whether the manager has DARA, IARA, or CARA. As with delta, the effect is negative with DARA, positive with IARA, and equal to zero with CARA. Thus, other things being equal, higher levels of vega should increase the incentive of managers with DARA to reduce cash holdings in favor of riskier investments. Higher levels of vega and the higher levels of wealth it implies should increase the incentive of managers with IARA to increase cash holdings at the expense of riskier investments. Higher levels of vega should have no effect on managers with CARA.

In the empirical model we include vega as an explanatory variable because of its potential effect on risk aversion through the wealth effect. We show that both vega and delta affect risk aversion in a similar manner. The effect is negative with DARA, positive with IARA, and equal to zero with CARA. Thus, if our analysis is correct, they should both have the same sign with respect to cash holdings.

### III. Data and Sample Construction

To carry out the empirical analysis, we collected executive compensation data and corporate governance data from the BoardEx database for a sample of UK firms listed on the London Stock Exchange for 2000–2004. BoardEx is a UK-based firm that provides biographical information on senior executives and board members of U.S. and European public and private firms. It also provides detailed information on the compensation (salaries, bonuses, pensions, long-term incentive plans, option, and share grants) of senior executives.

Additionally, the data on the market value of equity and the accounting data were collected from Datastream. Firms classified as financial firms were excluded from the sample (Standard Industry Classification codes between 8000 and 8999) because regulatory obligations require such companies to maintain specified cash holdings. The final unbalanced sample consists of 357 nonfinancial UK firms.

*Main Variables: Cash Holdings, CEO Delta, Change in CEO Delta, CEO Vega, and CEO Cash Compensation*

Cash holdings is measured as cash and marketable securities to total assets (*Cash\_Ta*). This definition is consistent with the corporate liquidity measure employed by Ozkan and

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<sup>15</sup> The Black–Scholes formula for the vega of a European call option is:

$$\frac{\partial f}{\partial \sigma} = x\sqrt{T-t} \frac{1}{\sqrt{2\pi}} e^{-\frac{(d_1)^2}{2}}.$$

<sup>16</sup> Other things being equal, the vega of a share is equal to zero. Like delta, the vega of managerial total wealth is a weighted average of the vegas of the individual shareholdings and options:

$$\text{vega} = \sum_i z_i \text{vega}_i.$$

Ozkan (2004) for their UK sample. The compensation data on the CEO is consistent with prior studies that use delta and vega (Guay 1999; Knopf, Nam, and Thornton 2002; Coles, Daniel, and Naveen 2006; Tong 2010). CEO vega is defined as the pound change in the CEO's firm-based wealth corresponding to a change of 1% in the volatility of stock returns (*CEO\_Vega*).<sup>17</sup> CEO delta is defined as the pound change in the CEO's firm-based wealth following a 1% change in the firm's stock price (*CEO\_Delta*).<sup>18</sup> The change in CEO delta is defined as [*CEO\_Delta<sub>T</sub>* – *CEO\_Delta<sub>T-1</sub>*] (*CEO\_Delta\_Chng*).<sup>19</sup> Finally, CEO salary and bonus is measured as annual direct cash compensation plus annual cash bonus (*CEO\_SalBon*). Following Guay (1999) and Coles, Daniel, and Naveen (2006), all compensation structures are measured in the thousands of dollars. Additional data collected from BoardEx include the total number of directors on the board and the number of nonexecutive directors on the board.

### Control Variables

The control variables employed in this study are all consistent with prior studies on corporate cash holdings. We first control for corporate governance mechanisms. The composition of board of directors is considered as a central firm mechanism for mitigating the agency costs stemming from the separation of ownership and control. Fama and Jensen (1983) describe the board of directors as the “apex body” of an organization's internal governance system, and Weisbach (1988) describes it as the shareholders' first line of defense against the incumbent management, or at least the second-best efficient solution (Hermalin and Weisbach 2003). Following previous studies, we control for the effectiveness of firm-level governance by board size and board independence. Board size is measured as the natural logarithm of the total number of directors on the board (*Bsize*), and board independence is measured as the ratio of total nonexecutive directors to total board members (*Nex%*).

Second, we include the following firm characteristics. The annualized standard deviation of daily stock returns proxies for firm risk (*Firm\_Risk*). Leverage is defined as the ratio of total debt to total assets (*Leverage*). We use the market-to-book ratio defined as the book value of assets, less the book value of equity, plus the market value of equity, divided by book value of assets to proxy growth opportunities (*Mktbv*). The natural logarithm of total assets is used as a proxy for firm size (*Firm\_Size*).<sup>20</sup> The ratio of capital expenditure to total assets measures the level of conservative investment policy engaged by the firm (*Capex-Ta*) and the ratio of the sum of research and development to total assets measures the level of risky investments engaged by the firm (*RDSAG-Ta*). The descriptive statistics for the variables are presented in Table 1.

The correlation matrix, presented in Table 2, shows some correlation between firm size and the compensation variables. We do not consider this correlation high enough to cause concern for issues related to multicollinearity. However, as a robustness test to

<sup>17</sup> We assume that the vega of outright shareholdings is equal to 0.

<sup>18</sup> The delta of outright shareholdings is equal to 1.

<sup>19</sup> The change in the delta of outright shareholdings is equal to 0.

<sup>20</sup> In unreported analysis, we measured firm size as the natural logarithm of net assets. The results are quantitatively and qualitatively similar to the results with firm size measured as the natural logarithm of total assets.

TABLE 1. Descriptive Statistics.

Variables	Mean	Std. Dev.	25th	Median	75th
<i>Cash_Ta</i>	0.135	0.166	0.032	0.079	0.166
<i>CEO_Vega</i>	23.063	160.242	0.223	1.253	3.812
<i>CEO_Delta</i>	94.289	400.952	9.000	22.000	56.000
<i>CEO_Delta_Chng</i>	-13.256	449.568	-13.000	3.000	15.000
<i>CEO_SalBon</i>	516.390	444.014	260.500	395.600	620.000
<i>Bsize</i>	2.084	0.311	1.946	2.079	2.303
<i>Nex%</i>	0.530	0.140	0.429	0.533	0.625
<i>Firm_Risk</i>	0.383	0.235	0.237	0.321	0.459
<i>Leverage</i>	0.227	0.214	0.072	0.201	0.327
<i>Mktbv</i>	2.071	2.612	1.119	1.447	2.121
<i>Firm_Size</i>	12.897	1.827	11.640	12.736	14.123
<i>Capex_Ta</i>	0.150	3.481	0.023	0.046	0.084
<i>RDSAG_Ta</i>	0.283	0.298	0.077	0.206	0.388

Note: *Cash\_TA* is the ratio of total cash and cash equivalents to total assets. *CEO\_Vega* is the dollar change in the CEO's option portfolio for a 0.01 change in stock return standard deviation measured in thousands. *CEO\_Delta* is the dollar change in CEO wealth for a 1% change in stock price, measured in thousands. *CEO\_Delta\_Chng* is the first difference of *CEO\_Delta*. *CEO\_SalBon* is the cash salary plus cash bonus compensation received by the CEO, measured in thousands. *Bsize* is the natural logarithm of total directors on the board. *Nex%* is the ratio of total nonexecutive directors on the board to total directors on the board. *Firm\_Risk* is the annualized standard deviation of year *t*'s daily stock return. *Leverage* is the ratio of total debt to total assets. *Mktbv* is measured as the book value of assets, less the book value of equity plus the market value of equity, divided by book value of assets. *Firm\_Size* is the natural logarithm of total assets. *Capex\_TA* is the ratio of capital expenditure to total assets. *RDSAG\_TA* is the ratio of research and development to total assets.

control for potential estimation bias, we orthogonalize firm size with respect to vega, delta, change in delta, and cash compensation by regressing firm size on these variables and saving the residuals as the orthogonalized firm size variable. In this way, we eliminate the collinearity but respect the integrity of the model. The results using the orthogonalized variable are quantitatively and qualitatively similar.

#### IV. Empirical Results

In the multivariate regression analysis used to examine the impact of CEO compensation structures on corporate cash holdings, one prominent issue is the potential endogeneity between cash holdings and the hypothesized determinants such as managerial compensation structures. In addition to endogeneity, another important issue that plagues previous studies on cash holdings (e.g., Chava and Purnanandam 2010; Liu and Mauer 2011; Tong 2010) is that these studies implicitly assume that firms can immediately adjust corporate cash holdings following changes in firm characteristics, compensation structures, and/or random shocks. However, in an imperfect market, adjustment and transaction costs may prevent firms from rapidly moving toward optimal cash holdings. This implies that the observed cash holdings may deviate from optimal levels for a period of time. For this reason we adopt a dynamic (partial target adjustment) cash holdings model by including the lagged dependent variable among the explanatory variables.

TABLE 2. Pearson Correlation Matrix.

Variables	CEO_Vega	CEO_Delta	CEO_Delta_Chng	CEO_SalBon	Bsize	Nex%	Firm_Risk	Leverage	Mktbv	Firm_Size	Capex_Ta	RDSAG_Ta
CEO_Vega	1											
CEO_Delta	0.218***	1										
CEO_Delta_Chng	0.042	0.514***	1									
CEO_SalBon	0.411***	0.265***	0.175***	1								
Bsize	0.285***	0.109***	0.049	0.530***	1							
Nex%	0.155***	-0.0569**	0.024	0.258***	0.110***	1						
Firm_Risk	0.298***	-0.064**	-0.205***	-0.139***	-0.031	0.102***	1					
Leverage	0.085***	-0.101***	0.009	0.204***	0.262***	0.169***	-0.074***	1				
Mktbv	0.024	0.317***	0.062**	0.012	-0.009	-0.063***	0.006	-0.173***	1			
Firm_Size	0.375***	0.105***	0.109***	0.733***	0.639***	0.276***	-0.086***	0.441***	-0.256***	1		
Capex_Ta	-0.020	0.031	0.042	-0.028	0.00	-0.032	-0.116	0.125	0.131	0.048	1	
RDSAG_Ta	-0.066**	0.022	-0.067**	-0.235***	-0.227***	-0.074***	0.090***	-0.208***	0.372***	-0.418***	-0.041*	1

Note: CEO\_Vega is the dollar change in the CEO's option portfolio for a 0.01 change in stock return standard deviation measured in thousands. CEO\_Delta is the dollar change in CEO wealth for a 1% change in stock price, measured in thousands. CEO\_Delta\_Chng is the first difference of CEO\_Delta. CEO\_SalBon is the cash salary plus cash bonus compensation received by the CEO, measured in thousands. Bsize is the natural logarithm of total directors on the board. Nex% is the ratio of total nonexecutive directors on the board to total directors on the board. Firm\_Risk is the annualized standard deviation of year  $t$ 's daily stock return. Leverage is the ratio of total debt to total assets. Mktbv is measured as the book value of assets, less the book value of equity plus the market value of equity, divided by book value of assets. Firm\_Size is the natural logarithm of total assets. Capex\_Ta is the ratio of capital expenditure to total assets. RDSAG\_Ta is the ratio of research and development to total assets.

\*\*\*Significant at the 1% level.

\*\*Significant at the 5% level.

\*Significant at the 10% level.

To account for the above-mentioned empirical issues, we use an instrumental variables estimation method, where the second lagged values of the endogenous variables are used as instruments. In particular, we employ the generalized method of moments (GMM) system estimator (Arellano and Bond 1991; Blundell and Bond 1998) for the following reasons. First, the dependent variable (*Cash\_Ta*) is dynamic, in the sense that it depends on previous realizations. Second, the panel consists of few periods (small  $T$ ) and a large number of firms (large  $N$ ). Third, the GMM system explicitly allows for heteroskedasticity and autocorrelation within firms. Furthermore, to account for the fact that the consistency of estimates is dependent on an optimal choice of instruments, where the validity of instruments is subject to the absence of higher order serial correlation among the idiosyncratic component of the error term, we include a test for second-order correlation. We also report the test statistic for the Hansen test (Hansen 1982) for overidentifying restrictions to indicate whether instruments and residuals are independent.

The results of the GMM system are reported in Table 3. We first estimated a cash holdings model without *CEO\_Delta\_Chng* variable, termed model 1. We then reestimated the model including *CEO\_Delta\_Chng* to gauge directly the effect of omitting it. This is termed model 2. By and large, the results presented in Table 3 provide significant evidence of the impact of CEO compensation sensitivities and, by extension, CEO risk incentives in determining cash holding policies.

The results of model 1 suggest that cash compensation (*CEO\_SalBon*) has a significant positive impact on cash holdings and *CEO\_Vega* has a significant negative impact on cash holding. On the other hand, *CEO\_Delta* does not affect cash holdings and this finding is consistent with prior studies such as Liu and Mauer (2011) and the majority of results presented by Tong (2010).

The results for model 2 question the robustness of the results obtained in model 1. When *CEO\_Delta\_Chng* is included, *CEO\_Delta* becomes significant, suggesting possible misspecification of the original model. *CEO\_Delta\_Chng* has the predicted sign and is significant. Based on the argument that CEOs can and do use cash holdings to manipulate the risk profile of the firm, the significant positive relation between the change in delta and cash holdings is evidence that CEO compensation incentives do affect CEO behavior through their effect on risk aversion as reflected in the effect of changes in delta on convexity and magnification in equations (10) and (11). With respect to the controversial relation between cash holdings and CEO delta, we report a highly significant negative relation at the 1% level. Based on equation (12), this suggests that the CEOs in our sample have utility functions with DARA.

Delta reflects the effect of risk aversion on cash holdings induced by changes in the firm's share price and its sign signals whether the utility function is DARA, IARA, or CARA. Vega reflects the effect of risk aversion on cash holdings induced by changes in the volatility of the firm's share price. Its sign also signals whether the utility function is DARA, IARA, or CARA. Thus, although the source of the effect differs from delta to vega, other things being equal, both variables should have the same sign. Vega is negative and significant at the 1% level, which is consistent with the findings of Chava and Purnanandam (2010) and Tong (2010). The negative relation between vega

**TABLE 3. Dynamic Panel Analysis of Corporate Cash Holdings on CEO Compensation Sensitivities, Corporate Governance Mechanisms, and Firm Characteristics.**

Variables	Model 1	Model 2
<i>Cash_TA<sub>t-1</sub></i>	0.60956 (.000)***	0.71385 (.000)***
<i>CEO_Vega</i>	-0.00054 (.000)***	-0.00021 (.001)***
<i>CEO_Delta</i>	-9.34e <sup>-06</sup> (.164)	-0.00005 (.000)***
<i>CEO_Delta_Chng</i>		0.00005 (.000)***
<i>CEO_SalBon</i>	0.00002 (.000)***	0.00001 (.000)***
<i>Bsize</i>	-0.03094 (.018)**	-0.05616 (.000)***
<i>Nex%</i>	0.05993 (.016)**	0.04223 (.032)**
<i>Firm_Risk</i>	0.00452 (.654)	0.01070 (.201)
<i>Leverage</i>	-0.01240 (.248)	-0.00419 (.526)
<i>Mktbv</i>	0.01332 (.000)***	0.01702 (.000)***
<i>Firm_Size</i>	-0.01493 (.000)***	-0.00467 (.187)
<i>Capex_TA</i>	-0.17658 (.000)***	-0.31036 (.000)***
<i>RDSAG_TA</i>	0.02447 (.005)***	0.02045 (.002)***
<i>N</i>	938	844
Wald Chi <sup>2</sup> -stat	6,575.12***	17,964.08***
AR(1)	-3.51***	-3.44***
AR(2)	-1.32	-0.58
Hansen test	132.10	125.83

Note: The dependent variable for regressions is *Cash\_TA*, measured as the ratio of total cash and cash equivalents to total assets. *Cash\_TA<sub>t-1</sub>* is the value of *Cash\_TA* lagged one period. *CEO\_Vega* is the dollar change in the CEO's option portfolio for a 0.01 change in stock return standard deviation measured in thousands. *CEO\_Delta* is the dollar change in CEO wealth for a 1% change in stock price, measured in thousands. *CEO\_Delta\_Chng* is the first difference of *CEO\_Delta*. *CEO\_SalBon* is the cash salary plus cash bonus compensation received by the CEO, measured in thousands. *Bsize* is the natural logarithm of total directors on the board. *Nex%* is the ratio of total nonexecutive directors on the board to total directors on the board. *Firm\_Risk* is the annualized standard deviation of year *t*'s daily stock return. *Leverage* is the ratio of total debt to total assets. *Mktbv* is measured as the book value of assets, less the book value of equity plus the market value of equity, divided by book value of assets. *Firm\_Size* is the natural logarithm of total assets. *Capex\_TA* is the ratio of capital expenditure to total assets. *RDSAG\_TA* is the ratio of research and development plus selling to total assets. Although not reported, models 1 and 2 include industry and year effects and a constant term. AR(1) and AR(2) are test statistics for first- and second-order autocorrelation in the residuals, respectively, distributed as standard normal  $N(0, 1)$  under the null of no serial correlation. Hansen test is a test of overidentifying restrictions, distributed as chi-square under the null of instrument validity. The *p*-values are presented in parentheses.

\*\*\*Significant at the 1% level.

\*\*Significant at the 5% level.

and cash holdings is consistent with the negative sign of delta and is further evidence of DARA.<sup>21</sup>

The significant negative coefficient on vega, in models 1 and 2 is evidence that higher volatility increases option-based wealth, and because managers have DARA, they are willing to reduce cash holdings in favor of the riskier investments. Ultimately, this result suggests that higher sensitivity to stock return volatility in managerial compensation reduces potential agency costs stemming from corporate cash holdings. The caveat is that this will be the case only if managers have DARA. Overall the findings highlight that vega and delta enhance managerial risk incentives, thereby reducing risk-related agency costs while the change in delta induces greater managerial risk aversion through its effect on convexity and magnification.

To be consistent with prior studies we also controlled for the effect of corporate governance mechanisms on cash holdings (see, e.g., Belghitar and Khan 2013). Board size (*Bsize*) has a highly significant negative relation with cash holdings, which is consistent with the arguments posited by Dalton, Johnson, and Ellstrand (1999) that larger boards are better equipped to monitor managerial actions and act in shareholder interest. Furthermore, the coefficient on board independence (*Nex%*) is positive and significant at the 5% level, and at the 1% in model (2). Yermack (1996) and Agrawal and Knoeber (1996) argue that such results might be indicative of nonexecutives lacking requisite skills necessary to monitor managers.

Turning to the other control variables, the coefficient of the one-period lagged value of cash holdings (*Cash\_Ta<sub>t-1</sub>*) is highly significant and positively related to current cash holding levels at the 1% significance level across all models. This highlights the importance of accounting for the dynamic nature of corporate cash holdings, as past levels have a direct influence on current levels of cash holdings. The coefficient of the growth opportunity set (*Mktbv*) is positive and highly significant at the 1% level. The coefficient of firm size (*Firm\_Size*) is negative and highly significant at the 1% level. The level of capital expenditure (*Capex\_Ta*) is documented as having a highly significant negative relation with cash holdings at the 1% level. Furthermore, there is evidence of a highly significant positive relation between the levels of research and development, selling, administrative and general expense, and cash holdings at the 1% level. Finally, there is no significant evidence that firm risk has any effect on cash holdings. These results are consistent with the findings documented by Kim, Mauer, and Sherman (1998), Opler et al. (1999), Ozkan and Ozkan (2004), Chava and Purnanandam (2010), Liu and Mauer (2011), and Tong (2010).

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<sup>21</sup> The different signs found by Liu and Mauer (2011) could be due to the omitted variable *Change in Delta*. It could also be due to the complicated relation between cash holdings and vega shown by Liu and Mauer, especially with respect to debt financing and liquidity covenants. Thus, besides the wealth-increasing risk incentive, our finding of a negative relation between vega and cash holdings could also reflect a lower incidence of debt financing and frequency of liquidity covenants due to the fact that UK credit markets are less sophisticated than those in the United States.

*Risk Environments, Risk Incentives, and Cash Holdings*

The effectiveness of managerial incentives may vary across organizational environments as it does in other governance mechanisms (Hutchinson and Gul 2004). For example, based on the plausible assumption that there is an upper limit on how much volatility a firm can profitably bear, for a given delta or vega, the scope for risk-increasing actions may be lower in higher risk firms. As a robustness check of the foregoing results, we investigate whether the effect of option-based incentives on cash holdings varies with respect to the risk environment of the firm. Coles, Daniel, and Naveen (2006) argue that targeting firm resources toward greater levels of research and development represents engagement in risky investment policies. Additionally, a more direct measure of the riskiness of a firm relates to the volatility of its stock returns. We use these two criteria to assess the impact of CEO compensation incentives on cash holdings in differing risk environments.

First, we split the sample into three categories. Firms with the ratio of research development, selling, administrative, and general expenses to sales (*RDSAG\_Sales*) less than the 40th percentile of the sample are classified as low-risk firms, and firms with *RDSAG\_Sales* greater than the 60th percentile of the sample *RDSAG\_Sales* are classified as high-risk firms. For robustness, the sample is also split on a similar basis into low-risk and high-risk subsamples using the annualized standard deviation of daily stock returns (*Firm\_Risk*). Models 1 and 2 are firm risk regressions using *RDSAG\_Sales* subsamples, and models 3 and 4 use *Firm\_Risk* subsamples.

Table 4 presents the results of the tests on the subsamples using the complete set of explanatory variables, which are comparable to the results of model 2 in Table 3. The results suggest that although the coefficients on delta, vega, and the change in delta for the subsamples have the same signs and remain statistically significant irrespective of the riskiness of the environment in which the firm operates, the size of the coefficients is smaller for the higher risk environments. This is evidence that although compensation incentives remain relevant for differing risk environments, the scope for risk-increasing actions is reduced for environments with higher risk. Overall, the findings speak to the strength of structuring managerial compensation based on the assumption of DARA irrespective of the operational environment's level of risk.

*The Executive Team, Risk Incentives, and Cash Holdings*

Some studies argue that that corporate decisions are often made in teams, which can change the decision making dynamics (see, e.g., Aggarwal and Samwick 2003). To account for the effect of other members of the firm's executive team of directors in shaping corporate cash holdings, we examine the impact of the average executive delta, average executive vega, and the change in the average executive delta on corporate cash holdings using the GMM system estimator. The results are presented in Table 5.

These results closely mirror the results presented in Table 3. The average executive vega is negative and significant at the 1% level across all models. The change in the average executive delta is positive and significant at the 1% level in models 1 and 2. In model 2 average executive delta is negative and significant at the 1% level. However, when the change in executive delta is omitted from the cash holding specification in model



**TABLE 4. Dynamic Panel Analysis of Cash Holdings on Firm Characteristics and CEO Compensation Sensitivities within Various Risk Environments.**

Variables	R&D		Firm Risk	
	High	Low	High	Low
	Model 1	Model 2	Model 3	Model 4
<i>Cash_Ta<sub>t-1</sub></i>	0.73936 (.000)***	0.79799 (.000)***	0.57516 (.000)***	0.75652 (.000)***
<i>CEO_Vega</i>	-0.00020 (.001)***	-0.00061 (.000)***	-0.00034 (.017)**	-0.00039 (.000)***
<i>CEO_Delta</i>	-0.00003 (.000)***	-0.00010 (.000)***	-0.00012 (.000)***	-0.00002 (.000)***
<i>CEO_Delta_Chng</i>	0.00003 (.000)***	0.00006 (.000)***	0.00007 (.000)***	0.00001 (.000)***
<i>CEO_SalBon</i>	0.00002 (.000)***	0.00002 (.000)***	8.38e <sup>-06</sup> (.000)***	1.97e <sup>-06</sup> (.643)
<i>Bsize</i>	-0.09601 (.000)***	0.01312 (.129)	-0.02120 (.000)***	-0.02142 (.003)***
<i>Nex%</i>	0.02275 (.029)**	0.12567 (.000)***	-0.04840 (.000)***	0.00760 (.546)***
<i>Firm_Risk</i>	-0.01703 (.002)***	0.01153 (.014)**	0.00880 (.006)***	0.09114 (.000)***
<i>Leverage</i>	0.05509 (.000)***	0.01528 (.254)	0.00679 (.001)***	-0.06001 (.000)***
<i>Mktbv</i>	0.01431 (.000)***	0.00767 (.000)***	0.01999 (.000)***	0.01803 (.000)***
<i>Firm_Size</i>	-0.00734 (.006)***	-0.01205 (.000)***	-0.00890 (.000)***	0.00653 (.000)***
<i>Capex_Ta</i>	-0.17803 (.000)***	-0.36011 (.000)***	-0.49063 (.000)***	-0.14289 (.000)
<i>RDSAG_Ta</i>	-0.02685 (.000)***	-0.04438 (.000)***	0.01144 (.000)***	0.04266 (.000)***
<i>N</i>	328	357	309	355
Wald Chi <sup>2</sup> -stat	5.33e <sup>06</sup> ***	2.25e <sup>07</sup> ***	2.53e <sup>06</sup> ***	80573.48***
AR(1)	-2.42**	-3.18***	-2.61***	-4.18
AR(2)	-0.47	0.43	-0.94	-0.03
Hansen test	91.49	105.74	114.65	125.76

Note: Models 1 and 2 are regression results for high *RDSAG\_Sales* firms (ratio of research development, selling, administrative, and general expenses to sales) and low *RDSAG\_Sales* firms, respectively. Models 3 and 4 present regression results for high *Firm\_Risk* (stock return volatility) firms and low *Firm\_Risk* firms, respectively. The dependent variable is *Cash\_TA* measured as the ratio of total cash and cash equivalents to total assets. *Cash\_TA<sub>t-1</sub>* is the value of *Cash\_TA* lagged one period. *CEO\_Vega* is the dollar change in the CEO's option portfolio for a 0.01 change in stock return standard deviation measured in thousands. *CEO\_Delta* is the dollar change in CEO wealth for a 1% change in stock price, measured in thousands. *CEO\_Delta\_Chng* is the first difference of *CEO\_Delta*. *CEO\_SalBon* is the cash salary plus cash bonus compensation received by the CEO, measured in thousands. *Bsize* is the natural logarithm of total directors on the board. *Nex%* is the ratio of total nonexecutive directors on the board to total directors on the board. *Firm\_Risk* is the annualized standard deviation of year *t*'s daily stock return. *Leverage* is the ratio of total debt to total assets. *Mktbv* is measured as the book value of assets, less the book value of equity plus the market value of equity, divided by book value of assets. *Firm\_Size* is the natural logarithm of total assets. *Capex\_Ta* is the ratio of capital expenditure to total assets. *RDSAG\_Ta* is the ratio of research and development to total assets. Although not reported, models 1–4 include industry and year effects and a constant term. AR(1) and AR(2) are test statistics for first- and second-order autocorrelation in the residuals, respectively, distributed as standard normal  $N(0, 1)$  under the null of no serial correlation. Hansen test is a test of overidentifying restrictions, distributed as chi-square under the null of instrument validity. The *p*-values are presented in parentheses.

\*\*\*Significant at the 1% level.

\*\*Significant at the 5% level.

**TABLE 5. Dynamic Panel Analysis of Corporate Cash Holdings on Executive Team Compensation Sensitivities, Corporate Governance Mechanisms, and Firm Characteristics.**

Variables	Model 1	Model 2
<i>Cash_TA<sub>t-1</sub></i>	0.53829 (.000)***	0.66559 (.000)***
<i>A_Vega</i>	-0.00003 (.000)***	-0.00002 (.000)***
<i>A_Delta</i>	6.84e <sup>-06</sup> (.717)	-0.00003 (.000)***
<i>A_Delta_Chng</i>		0.00002 (.000)***
<i>A_SalBon</i>	0.00003 (.000)***	0.00002 (.000)***
<i>Bsize</i>	-0.04377 (.002)***	-0.03699 (.004)***
<i>Nex%</i>	0.12008 (.000)***	0.03834 (.075)*
<i>Firm_Risk</i>	0.01947 (.047)**	0.02180 (.010)***
<i>Leverage</i>	-0.04995 (.002)***	0.00161 (.877)
<i>Mktbv</i>	0.01437 (.000)***	0.01329 (.000)***
<i>Firm_Size</i>	-0.02109 (.000)***	-0.01496 (.000)***
<i>Capex-Ta</i>	-0.15695 (.000)***	-0.33404 (.000)***
<i>RDSAG-Ta</i>	0.00967 (.356)	-0.02241 (.016)**
<i>N</i>	1272	1202
Wald Chi <sup>2</sup> -stat	6759.82***	11148.89***
AR(1)	-4.43***	-4.51***
AR(2)	-0.83	-0.12
Hansen test	113.93	117.96

Note: The dependent variable for models 1 and 2 is *Cash\_TA*, measured as the ratio of total cash and cash equivalents to total assets. *Cash\_TA<sub>t-1</sub>* is the value of *Cash\_TA* lagged one period. *A\_Vega* is the average dollar change in executive option portfolio for a 0.01 change in stock return standard deviation, among executive members of the board measured in thousands. *A\_Delta* is the average dollar change in executive wealth for a 1% change in stock price, among executive member of the board measured in thousands. *A\_Gamma* is the first difference of *A\_Delta*. *A\_SalBon* is the average cash salary compensation received by executive member of the board, measured in thousands. *Bsize* is the natural logarithm of total directors on the board. *Nex%* is the ratio of total nonexecutive directors on the board to total directors on the board. *Firm\_Risk* is the annualized standard deviation of year *t*'s daily stock return. *Leverage* is the ratio of total debt to total assets. *Mktbv* is the ratio of book value of total assets minus the book value of equity plus the market value of equity to the book value of total assets. *Firm\_Size* is the natural logarithm of total assets. *Capex-Ta* is the ratio of capital expenditure to total assets. *RDSAG-Ta* is the ratio of research and development expenses to total assets. Although not reported, models 1 and 2 include a constant, industry, and year effects. AR(1) and AR(2) are test statistics for first- and second-order autocorrelation in the residuals, respectively, distributed as standard normal  $N(0, 1)$  under the null of no serial correlation. Hansen test is a test of overidentifying restrictions, distributed as chi-square under the null of instrument validity. The *p*-values are presented in parentheses.

\*\*\*Significant at the 1% level.

\*\*Significant at the 5% level.

\*Significant at the 10% level.

1, delta becomes insignificant as it did in model 1 of Table 3, further evidence of the complementary relation between the two. Finally, the average executive cash compensation has a significant positive relation between cash holdings across all models in Table 5 at the 1% level.

## V. Conclusion

We used the parameters of the Black–Scholes option pricer and the results of Ross (2004) with respect to the effects of option-based convexity, magnification, and translation to examine the relation between managerial compensation incentives and corporate decision making. We show that the convexity and magnification effects reduce managerial risk aversion, but these effects are diminished as delta increases. The implication is that the alignment of managerial and shareholder interests that comes about through lower risk aversion that induces managers to lower cash holdings in favor of riskier assets is reduced by increases in delta. We also show that delta is a significant determinant of the translation effect. For utility functions with DARA its effect is negative. Its effect is positive with IARA and neutral with CARA. Although vega does not appear directly as a determinant of managerial risk aversion in the three effects outlined above, it can affect risk aversion indirectly through its effect on managerial wealth. As with delta, the effect is negative with DARA, positive with IARA, and equal to zero with CARA. The implication is that the effect of delta and vega on cash holdings depends on whether the manager has DARA, IARA, or CARA.

The empirical testing provides evidence that supports the model developed in Section II. Our results show that there is a significant positive relation between changes in delta and cash holdings, which is evidence that changes in delta reduce the effects of magnification and convexity on managerial risk aversion. We also provide evidence that there is a significant negative relation between the option delta and cash holdings. This implies that UK managers generally exhibit DARA. This implication is reinforced by the significant negative relation between vega and cash holdings. Although vega is not a direct determinant of risk aversion, the effect of the wealth-increasing risk incentive suggests that vega and cash holdings should be negatively correlated. Liu and Mauer (2011), however, show that the relation between vega and cash holdings is much more complicated than the simple wealth-increasing risk incentive suggests, especially with respect to debt financing and liquidity covenants, and that in the United States this relation is positive. Thus, besides the wealth-increasing risk incentive, our finding of a negative relation between vega and cash holdings could also reflect a lower incidence of debt financing and frequency of liquidity covenants due to the fact that UK credit markets are less sophisticated than those in the United States.<sup>22</sup> Finally, there is evidence that larger cash compensation to managers heightens agency problems because of differing risk preferences between managers and shareholders. As such, greater managerial cash compensation encourages managers to engage in risk-averse policies by increasing cash

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<sup>22</sup> We thank an anonymous referee for this insight.

holdings. These results are robust to alternative specifications, when incentives are extended to include all executive board members and when the sample is broken down according to different risk characteristics.

By taking into consideration the convexity, magnification, and translation effects, this article offers insights into the whys and wherefores of the mixed results in the literature cited above. Because the signs on vega and delta depend on whether the managerial utility function is DARA, IARA, or CARA, the different signs and levels of significance in the samples could be due to different utility functions. For example, in one sample DARA might predominate, resulting in a significant negative relation between vega and delta and risk aversion. In another it might be IARA that predominates, resulting in a positive relation. Where CARA predominates there would be no significant relation. The different significance levels could also be due to different mixtures of utility functions. For example, DARA functions and IARA functions could have offsetting effects, thereby reducing or eliminating statistical significance. The mixed results could also be due to an omitted variable problem. We have shown that the change in delta is a key explanatory variable that affects the magnitude and significance of vega and delta. Because none of the previous studies includes this variable, it is safe to suppose that their results have been affected.

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